FORECASTED CHRONOLOGICAL POWER FLOW FOR ENABLING TIMELY DYNAMIC TARIFF ACTIVATION

Ricardo GONÇALVES
EDP Distribuição – Portugal
ricardonuno.goncalves@edp.pt

Miguel LOURO
EDP Distribuição – Portugal
Miguel.Louro@edp.pt

André PAULO
EDP Distribuição – Portugal
andre.paulo@edp.pt

Pedro FERREIRA
EDP Inovação – Portugal
Pedro.ferreira@edp.pt

Marco PINHEIRO
EDP Inovação – Portugal
Marco.pinheiro@edp.pt

Margarida PEDRO
EDP Inovação – Portugal
Margarida.pedro@edp.pt

Luís Marcelino FERREIRA
Ambertree – Portugal
Marcelino.ferreira@ambertree.pt

Pedro CARVALHO
Ambertree – Portugal
Pedro.carvalho@ambertree.pt

Fernando CARVALHO
Ambertree – Portugal
Fernando.carvalho@ambertree.pt

Tiago SANTOS
Ambertree – Portugal
Tiago.santos@ambertree.pt

ABSTRACT

The introduction of sensors and smart meters in power networks has leveraged the use of several other technologies with the aim of improving efficiency of grid operation and maximizing the benefit for all the stakeholders. One way to improve efficiency is to foster a better utilization of the existing assets which delays the investment on new ones. Dynamic tariffs are tariffs whose prices change as a function of certain constraints (time-related or network operation-related). The goal of their utilization is to try to induce a load shift from peak periods thus decreasing the peak value.

In order to anticipate the need of shifting load, besides a favourable regulatory environment and the adherence of consumers to this kind of strategies, the Distribution System Operator (DSO) needs to forecast when, in the future, will a peak period occur. To do so, it is needed to develop load and generation forecasting models, scale them on Big Data Infrastructures and integrate the results into power networks analysis tools capable of processing the amount of data within the time constraints for the analysis (if it takes too long to process the information may be useless).

INTRODUCTION

Soon, power distribution networks will be managed proactively, rather than reactively. This proactiveness will be possible due to advancements in Artificial Intelligence and in Information Systems, which will allow DSO to anticipate and prevent negative impacts resulting from overloads or over/undervoltages.

Accurate forecasting is an essential condition for the DSO to proactively manage the power network and to implement delay investments strategies, by issuing signals to load or generation aiming at a better utilizing of distribution network assets. Entidade Reguladora dos Serviços Energéticos (ERSE), the Portuguese regulator, has given the first steps to obtain knowledge regarding DSO activation of flexibility resources (namely load), by proposing a dynamic tariffs pilot-project. Within the scope of this project, the DSO has the possibility to increase or decrease the network access tariff if network power flow reaches its peak or is in an empty hour. This is performed by geographical zone as the load patterns may differ from region to region.

Supporting the dynamic tariffs pilot project requires a good forecasting tool to determine the expected load with a three-day horizon. However, the Portuguese network has about ~100.000 HV and MV connection points either to load, generation or LV networks. This requires a large computational capability to carry out the forecast. This was accomplished by the PREDIS Big Data Infrastructure, developed by EDP Inovação.

This is only part of the problem, because the network can have topological changes which can shift load from one substation to another and unexpected power flows, on the other hand the power flow can cause overloads in lines which are not necessarily located in the geographical location responsible for the power increase. For a healthy system operation, a power flow tool that has the capability to simulate the entire HV and MV network is needed. This required developing the existing Power Flow structure used by EDPD (DPLAN) to support the entire HV and MV Portuguese network (~2 million nodes) and to use the forecast from the 100k points provided by PREDIS to calculate a chronological (time periods of 15 minutes) power flow for the 3 days ahead.

After connecting PREDIS to DPLAN, it was possible to obtain power flow forecast for all HV and MV branches which enables the DSO with tools to meet challenges that

are already arising. The main use cases that can be supported by chronological forecasted power flow are: dynamic tariff activation; optimized planned outages; contingency analysis; optimized outage management; overload forecast; over/under voltage forecast.
This paper presents the need for power flow forecast to support activities related to dynamic tariffs which was developed to be used within the scope of the 2018. Unfortunately, the price signal part of the dynamic tariffs project was not able to proceed due to the difficulty of convincing clients to participate in new strategies for the grid that will ultimately bring benefits for all grid users.
This paper also describes the data strategy that EDPD, along with EDP Inovação and AmberTree conceived to tackle this need.

DYNAMIC TARIFFS

ERSE, the Portuguese regulator, decided to implement a pilot for dynamic tariffs, focusing on the tariff for the Use of High Voltage (HV) and Medium Voltage (MV) Distribution Networks, where most of high consumption clients are connected. The goal was to induce customer behaviours that would ultimately benefit power grid management, the environment and society, essentially by shifting load from peak hours to adjacent hours. This shift would allow – not only, but mainly – the delay of investments on the power network, which would have positive consequences on its overall usage: increased efficiency would lead to a more cost-effective network [1].
Several countries have been trying different ways of inducing the needed shift. For instance, in the United States, Gulf Power implemented a Critical Peak Pricing strategy and was able to achieve a peak reduction of 20 MW in Summer, which represented a decrease between 12 to 15% in power consumption [1].
Adopting a different strategy, France implemented a system which classifies each day in one of three options, each of them with different costs for power consumption during peak hours. It was estimated that this system led to a consumption reduction between 15% and 45% [1].

Types of Dynamic Tariffs

There are several options to implement dynamic tariffs, in this section, we present the most relevant.

Real Time Pricing

The participants in this tariff system are informed on the tariff prices in near-real time [1]. This forces a strong and frequent interaction between the consumer and is energy supplier. Also, due to the great volatility in the prices, it is expected for the monthly expenditure to also be very volatile.

Critical Peak Pricing

In this case, the tariff prices are adjusted in response to events or special conditions that has been identified has harmful to the power grid [1]. This adjustment leads the price to become much higher than the price on other periods of the day, thus forcing the consumers which have enough flexibility to shift their load.

Critical Peak Rebate

In this case, when the power grid is operating at its peak there's another strategy to make consumers shift their load: offer them benefits [1]. This is the main difference between this option and the previous one: the consumer who shuts down his devices or finds a way to reduce his consumption during critical periods is offered a discount on the tariff.

Direct Load Control

This option involves the direct control of the consumer's load by the DSO [1]. During periods in which the distribution network is operating at its peak, the DSO would have the possibility of directly turning off equipment, to reduce the overall system's load.
Of course, this is all done based on a previously arranged agreement, which would guarantee benefits or discounts to the adherent consumers.

The Portuguese Case

In 2017, ERSE presented two pilot projects on dynamic tariffs to the several stakeholders involved in the Portuguese Electrical Power System. These two pilots would be developed and implemented in 2018 to evaluate the effects of a broad, future implementation of a dynamic tariff system, which, among others, would allow the delay of investments, thus benefitting the whole system.

Pilot I

The first of these two pilot projects purposed by the Portuguese regulator presents a tariff system divided in four or six periods per day, differentiated by day of the week and month of the year. Each of these periods has a different price for the tariff, thus inducing the load shift by increasing the price of peak hours and decreasing the price of other periods, traditionally more favorable to the power grid.
The next figure shows a glimpse of the current periods of the day for Pilot I for inland Portugal, presented in [2], a public document issued by ERSE.

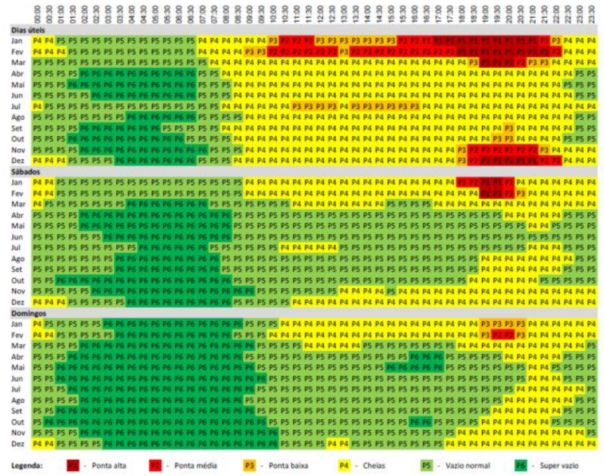

Figure 1. Current daily periods.

The next figure presents the change during Pilot 1 for the adherent consumers.

Figure 2. Daily periods for Pilot I.

As in Pilot I, the prices of the tariffs are defined *a-priori*, there is no need for the *apriori* intervention by the DSO.

Pilot II

This second pilot presented a clear case of a Critical Peak Pricing type of dynamic tariffs, in which the price of the peak hours tariff would be significantly higher than on other periods of the day. This price increase would happen only during times during which the distribution network was at risk of facing overloads or types of constraints. In other words, the price of the tariffs would increase only when the grid was expected to be operating near a critical state.

The expectation of this critical state is the essence of this paper, since, if Pilot II had come to life, there would have been a need for EDPD to predict, three days ahead, that it was expecting its power grid to be operating in critical conditions. Based on this estimation, a Critical Period would have been declared and the adherent consumers would be notified of the existence of such period and its extension.

This information was of utmost importance, since it would allow the adherent customers to make preparations in order to avoid paying extra fees for their energy consumption. Those preparations, in theory, would materialize in the so-needed load shifting. So, when the time of the Critical Period arrived, it was expected for the predicted load to be partially shifted to other periods. This decrease would then benefit the power grid by allowing it to operate in a normal state, rather than in its predicted critical one.

Given these restrictions, besides the need of a way to forecast power flow, the DSO would have to define a threshold, per region, above which a certain period with a certain forecast would be considered critical to the power grid operation. To achieve this threshold, a study was done on data of 2015, 2016 and 2017. The data belonged to the following features.

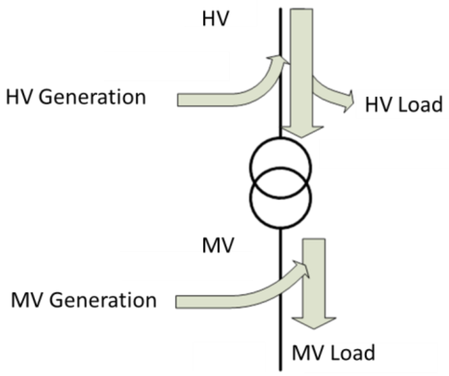

Figure 3. Variables studied during the definition of the needed thresholds.

The study involved the simulation of Pilot II applied to the data mentioned above and led to the following conclusion: if the power load predicted with a three-day delay of a certain region of the distribution network was above 90% of the peak load for that region in the previous year, a Critical Period should be declared.

Given this the expectation at the time for Pilot II to be carried out, it was needed for EDPD to develop a Power Flow forecast.

Implementation of Dynamic Tariffs

Pilot II was designed under the assumption of voluntary client participation (a reward system was designed to facilitate this). The project was presented to key stakeholders and a generous amount of time was given for clients to express their willingness to participate in Pilot II. However, despite best efforts by all involved entities, client participation fell short of the threshold defined by ERSE to continue with Pilot II. Therefore, ERSE decided that only Pilot I was to be implemented, leaving Pilot II out of its first initiative regarding dynamic tariffs.

Despite this and identifying the need for power flow forecast to perform and improve its operational activities, EDPD decided to keep the project ongoing.

POWER FLOW FORECAST

The problem of Load and Generation Forecast is a well-known problem that allows the Power Systems operators to plan for the days ahead and to avoid constraints in grid management. In this case, this paper focusses essentially on avoiding overloads and over/under voltages. To forecast those, the strategy is based on a power flow that runs with the forecasts of the load and generation of each connection point of the HV and MV distribution network.

A Big Data Problem

Dealing with ~100 thousand load and/or generation nodes on the distribution network, EDPD needed to find a way to develop models that could carry out forecasts in a distributed manner. Otherwise, the time required for a central processing unit to develop a model and a forecast would be insufficient. This, of course, was not practical for an everyday usage, such as the case with Pilot II, in which EDPD would need to daily produce forecasts.

So, the solution was to use a project that had been running in EDP Inovação for some time named PREDIS. This project developed a distributed Big Data system on top of Apache Hadoop, which holds the historical data of each of those ~100 thousand nodes, as well as other relevant information, namely, weather data.

To facilitate the access and retrieval of information, an HBase module was constructed on top of Hadoop. HBase is a non-relational database, column-oriented, and in this case, it has been used to store the load/generation diagrams per node, as well as weather information.

Load and Generation Forecast Models

On a first iteration of this project and due to a heavy focus on building the much-needed Big Data Infrastructure, the models developed by EDP Inovação were still at an initial stage. Thus, there's a lot of ground to cover to improve the results achieved presently.

However, it has been already possible to develop and deploy models for load forecast as well as for wind, solar PV, hydropower and thermal power generation. The deployment of those models is based on Apache Hadoop YARN, the Hadoop resource manager which allocates processing units to tasks. In this case, the tasks were the training or running of the Machine Learning models developed, for each node of the power grid.

The Machine Learning models used at this stage were Generalized Additive Models and the features used vary according to the type of problems tackled: load forecast, wind generation forecast, solar PV forecast, hydropower generation and thermal power generation.

Soon, the work load of this project will focus on improving the existing Machine Learning models and to leverage the information to further improve power grid operation efficiency.

Integration with Power Flow Systems

DPLAN is a computational system for the analysis of electricity distribution networks. Among other activities, DPLAN performs power flow analysis, by integrating data from several sources, including asset data and sensor data. This software has been in use for several years now at EDPD. Due to the identified needs for Pilot II of ERSE, a set of changes were implemented in the DPLAN system.

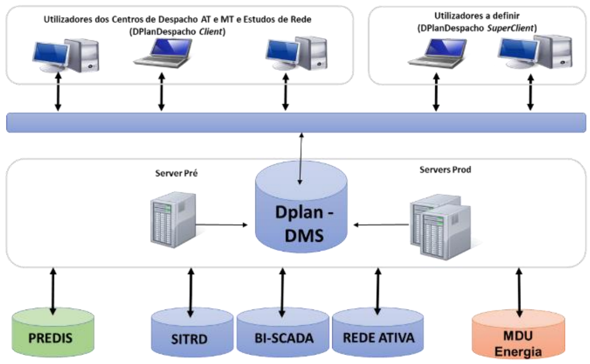

Figure 4. DPLAN architecture.

As seen in Figure 3, there's a data source called PREDIS, which is exactly the Big Data Infrastructure we described previously on this paper. With the addition of this new data source and the need to be able to compute it also led to the development of the so called DPLAN Super Client, which is an improved version of the regular DPLAN Client, capable of running a power flow analysis over the entire Portuguese Distribution Network (comprised of about 1,7 million nodes). This change involved a conversion from 32-bits to 64-bits, the review of data models and internal in-memory procedures, as well as the reconstruction of the power flow module.

Figure 5 gives a glimpse of the new process flow on DPLAN, which includes gathering PREDIS data (both sensor and weather data), running power flow module and storing the results.

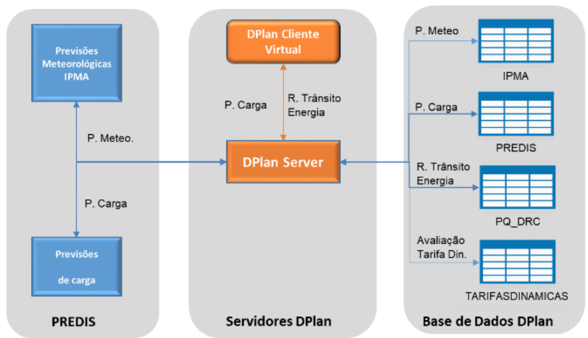

Figure 5. DPLAN process flow to incorporate PREDIS data.

RESULTS

Even though ERSE decided not to implement Pilot II of Dynamic Tariffs, there system developed is already presenting results.

Both the PREDIS Big Data Infrastructure and its interface with DPLAN is working as can be seen in Figure 5, which shows an example of the predicted voltage diagram for a certain node of the power network.

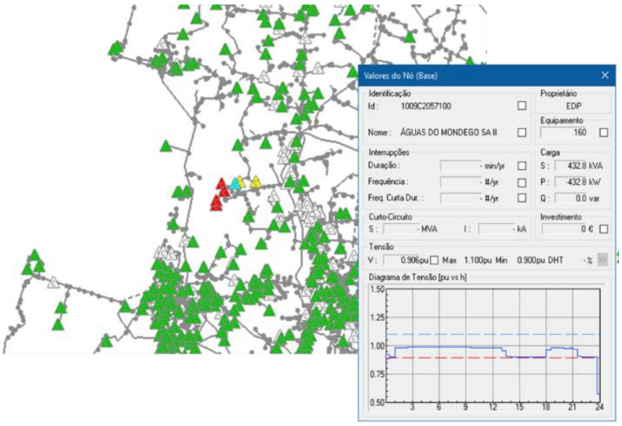

Figure 6. DPLAN power flow results based on the machine learning models output that run on top of PREDIS Big Data Infrastructure (green means no constraints).

This approach has shown to be very promising in forecasting the network's power flow and can be run for the entire EDPD HV and MV network in a very short time.

CONCLUSIONS

Flexibility tools such as dynamic tariffs have been discussed in the past years at an academic level but are now beginning to appear in the day to day management of distribution networks. This creates a challenge for DSO that must cope with many data points (much larger than the corresponding transmission network).

In this paper, the approach being carried out by EDPD to cope with future flexibility challenges, such as dynamic tariffs, has been presented. Big Data platforms can be effectively used to determine large number of forecasts (3-day load diagram for ~100k connection points). Furthermore, the use of a flexible chronological power flow that can handle large networks is also essential to accurately estimate overloads and over/under voltages.

The first results being generated by the system have shown to be very promising in determining voltages and load flow for every network node and branch.

REFERENCES

[1] J.T. Saraiva, J.N.M. Fidalgo, R.A. Soares, 2015, *Tarifas Dinâmicas – Relatório de Progresso*, Centro de Sistemas de Energia – INESC TEC, Porto, Portugal, 2015.

[2] Entidade Reguladora dos Serviços Energéticos, 2017, *PROJETOS-PILOTO PARA APERFEIÇOAMENTO DA ESTRUTURA TARIFÁRIA E INTRODUÇÃO DE TARIFAS DINÂMICAS*, Entidade Reguladora dos Serviços Energéticos, Porto, Portugal, 2017.